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1	WHA	AT 15 CLAIMED 15:
2		
3	1.	A method of controlling movement in a dynamic system which can be expressed
4		in terms of both rigid and flexible modes, the method comprising the steps of:
5		generating a rigid body input for the dynamic system;
6		processing the rigid body input so as to produce a processed input which
7		compensates for vibrations in the flexible mode of the system; and
8		applying the processed input to control the dynamic system.
9		
10	2.	A method according to Claim 1, wherein the generating step comprises (i)
11		creating a model of the rigid mode of the dynamic system based on a modal
12		analysis, and (ii) determining the rigid body input based on the modal analysis.
13		
14	3.	A method according to Claim 1, wherein the rigid body input corresponds to a
15		fundamental limiting parameter of the system, the fundamental limiting parameter
16		of the system comprising a first parameter of the system to enter into saturation.
17		
18	4.	A method according to Claim 3, wherein the processing step processes the rigid
19		body input in accordance with a system vibration limiting constraint and a system
20		sensitivity constraint.
21		
22	5.	A method according to Claim 4, wherein the system vibration limiting and
23		sensitivity constraints reduce vibration during movement of a component of the
24		dynamic system by less than 100%.
25		
26	6.	A method according to Claim 1, wherein the processing step processes the rigid
27		body input in accordance with one or more constraints that are a function of a

movement distance of a component of the dynamic system.

1	7.	A method according to Claim 1, wherein the processing step processes the rigid
2		body input in accordance with a system vibration limiting constraint only.
3		
4	8.	A method according to Claim 1, wherein the processing step shapes the rigid body
5		input using a predetermined shaping function.
6		
7	9.	A method according to Claim 8, wherein the rigid body input includes both
8		transient portions and a steady state portion; and
9		wherein only the transient portions of the rigid body input are shaped in
10		accordance with the predetermined shaping function.
11		
12	10.	A method according to Claim 1, wherein the processing step processes the rigid
13		body input by filtering the input using filters having zeros which are substantially
14		near poles of the system.
15		
16	11.	A method according to Claim 1, wherein the processing step processes the rigid
17		body input in accordance with at least one of constraints relating to system
18		thermal limits, system current limits, and system duty cycle.
19		
20	12.	A method according to Claim 1, wherein the processing step processes the rigid
21	r	body input by determining a movement distance of a component of the dynamic
22		system and modifying the rigid body input based on the movement distance.
23		
24	13.	A method according to Claim 1, wherein the rigid body input comprises a
25		Posicast input.
26		
27	14.	A method according to Claim 1, wherein the rigid body input comprises a
28		symmetric input.
29		

1	15.	A method according to Claim 1, wherein the processing step processes the rigid
2		body input in accordance with a symmetric constraint that varies as a function of
3		at least one of time and position of a component of the dynamic system.
4		
5	16.	A method according to Claim 1, wherein the rigid body input comprises a voltage
6		which has been controlled by controlling current.
7		
8	17.	A method according to any one of Claims 1 to 16, wherein the processing step
9		comprises:
10		identifying system parameters in real-time; and
11		modifying the rigid body input in real-time in accordance with the system
12		parameters identified in the identifying step.
13		
14	18.	A method according to Claim 2, wherein the determining step determines the
15		rigid body input in accordance with an insensitivity constraint.
16		
17	19.	A method according to Claim 2, wherein the model of the system comprises a
18		plurality of equations for the system; and
19		wherein an insensitivity constraint for a particular system parameter is
20		added to the system by taking a derivative of a system equation with
21		respect to the insensitivity constraint and setting the derivative equal to
22		zero.
23		
24	20.	A method according to Claim 2, wherein the model of the system comprises a
25		plurality of equations for the system; and
26		wherein an insensitivity constraint for a particular system parameter is
27		added to the system by setting a series of constraints for different values of
28		the system parameter so as to limit a variation in the system parameter.
29		

1	21.	A method according to Claim 2, wherein the rigid body input is determined in
2		accordance with a feedback signal; and
3		wherein the method further comprises adding a quasi-static correction
4		factor to the feedback signal, the quasi-static correction factor correcting
5		for a deflection in the component during movement.
6		
7	22.	A method according to Claim 2, further comprising determining a center of mass
8		of a component of the dynamic system;
9		wherein the rigid body input is determined in accordance with a feedback
10		signal based on the center of mass of the component.
11		
12	23.	A method of determining plural switch times for a voltage input to a dynamic
13		system having plural modes, the method comprising the steps of:
14		generating a model of the dynamic system based on a modal analysis of
15		each of the plural modes;
16		determining a response of the dynamic system in terms of the modal
17		analysis in the model;
18		determining an expression for a contribution of each of the plural modes to
19		a final location of the system based on a corresponding response, the
20		contribution of each mode of the system being based on switch times for
21		the voltage input;
22		estimating values relating to the plural switch times; and
23		calculating approximations of the values relating to the plural switch times
24		based on the estimated values using the expression for the contribution of
25		each of the plural modes and the modal analysis in the model of the
26		dynamic system.
27		,
28	24.	A method according to Claim 23, further comprising the step of re-calculating
29		approximations of the values based on a previous approximation the values.
30		

1	25.	A method according to Claim 24, wherein the re-calculating step is repeated a
2		plurality of times, each time using a re-calculated approximation of the values as
3		the previous approximation of the values.
4		
5	26.	A method according to Claim 23, further comprising the step of generating a table
6		comprising plural switch times;
7		wherein the estimating step comprises estimating the values using the
8		table.
9		
10	27.	A method according to Claim 23, further comprising the step of generating at
11		least one curve corresponding to the plural switch times;
12		wherein the estimating step comprises estimating the values using the at
13		least one curve.
14		
15	28.	A method according to Claim 23, wherein the dynamic system comprise a data
16		storage device; and
17		wherein the voltage inputs comprise voltage inputs to the data storage
18		device.
19		
20	29.	A method according to Claim 23, further comprising the step of performing input
21		shaping on the voltage input after switch times therefor have been calculated.
22		
23	30.	A method according to Claim 23, wherein the estimating step is performed using
24	•	a parameter estimator.
25		
26	31.	A method of reducing unwanted vibrations in a dynamic system, the method
27		comprising the steps of:
28		determining whether greater than a predetermined level of vibrations will
29		be excited by a system input; and

1		modifying the input to the dynamic system in a case that greater than the
2		predetermined level of vibrations will be excited, where the input to the
3		dynamic system is modified so as to reduce the level of vibrations in the
4		system to less than the predetermined level of vibrations
5		
6	32.	A method according to Claim 31, wherein the modifying step comprises using at
7		least one of an input shaper, an inverse shaper, and a filter in order to modify the
8		input to the dynamic system.
9		
10	33.	An apparatus which controls a dynamic system that can be expressed in terms of
11		both rigid and flexible modes, the apparatus comprising:
12		a memory which stores computer-executable process steps; and
13		a processor which executes the process steps stored in the memory so as
14		(i) to generate a rigid body input for the dynamic system, (ii) to process
15		the rigid body input so as to produce a processed input which compensates
16		for vibrations in the flexible mode of the system, and (iii) to apply the
17		processed input to control the dynamic system.
18		
19	34.	An apparatus according to Claim 33, wherein the processor generates the rigid
20		body input by (i) creating a model of the rigid mode of the dynamic system based
21		on a modal analysis of the system, and (ii) determining an input to the dynamic
22		system based on the modal analysis,
23		
24	35.	An apparatus according to Claim 32, wherein the rigid body input comprises a
25		fundamental limiting parameter of the system, the fundamental limiting parameter
26		of the system corresponding to a first parameter in the system to enter into
27		saturation.
28		

1	36.	An apparatus according to Claim 35, wherein the processor processes the rigid
2		body input in accordance with a system vibration limiting constraint and a system
3		sensitivity constraint.
4		
5	37.	An apparatus according to Claim 36, wherein the system vibration limiting and
6		sensitivity constraints reduce vibration during movement of the component by
7		less than 100%.
8		
9	38.	An apparatus according to Claim 33, wherein the processor processes the rigid
10		body input in accordance with one or more constraints that are a function of a
11		movement distance of a component of the dynamic system.
12		
13	39.	An apparatus according to Claim 33, wherein the processor processes the rigid
14		body input in accordance with a system vibration limiting constraint only.
15		
16	40.	An apparatus according to Claim 33, wherein the processor shapes the rigid body
17		input using a predetermined shaping function.
18		
19	41.	An apparatus according to Claim 40, wherein the rigid body input includes both
20		transient portions and a steady state portion; and
21		wherein the processor shapes only the transient portions of the rigid body
22		input in accordance with the predetermined shaping function.
23		
24	42.	An apparatus according to Claim 33, wherein the processor processes the rigid
25		body input by filtering the input using filters having zeros which are substantially
26		near poles of the system.
27		
28	43.	An apparatus according to Claim 33, wherein the processor processes the rigid
29		body input in accordance with at least one of constraints relating to system
30		thermal limits system current limits and system duty cycle

~ ; in

1		
2	44.	An apparatus according to Claim 33, wherein the processor processes the rigid
3		body input by determining a movement distance of a component of the dynamic
4		system and modifying the input based on the movement distance.
5		
6	45.	An apparatus according to Claim 33, wherein the rigid body input comprises a
7		Posicast input.
8		
9	46.	An apparatus according to Claim 33, wherein the rigid body input comprises a
10		symmetric input.
11		
12	47.	An apparatus according to Claim 33, wherein the processor processes the rigid
13		body input in accordance with a symmetric constraint that varies as a function of
14		at least one of time and position of a component of the dynamic system.
15		
16	48.	An apparatus according to Claim 33, wherein the processor processes the rigid
17		body input based on a voltage which has been controlled by controlling current.
18		
19	49.	An apparatus according to any one of Claims 33 to 48, wherein the processor
20		processes the rigid body input by (i) identifying system parameters in real-time,
21		and (ii) modifying the input in real-time in accordance with the system parameters
22		identified by the processor.
23		
24	50.	An apparatus according to Claim 33, wherein the processor generates the rigid
25		body input in accordance with an insensitivity constraint.
26		
27	51.	An apparatus according to Claim 50, wherein the model of the system comprises a
28		plurality of equations for the system; and
29		wherein an insensitivity constraint for a particular system parameter is
30		added to the system by taking a derivative of a system equation with

1		respect to the insensitivity constraint and setting the derivative equal to
2		zero.
3		
4	52.	An apparatus according to Claim 50, wherein the model of the system comprises a
5		plurality of equations for the system; and
6		wherein an insensitivity constraint for a particular system parameter is
7		added to the system by setting a series of constraints for different values of
8		the system parameter so as to limit a variation in the system parameter.
9		
10	53.	An apparatus according to Claim 33, wherein the processor generates the rigid
11		body input in accordance with a feedback signal; and
12		wherein the processor adds a quasi-static correction factor to the feedback
13		signal, the quasi-static correction factor correcting for a deflection in the
14		component during movement.
15		
16	54.	An apparatus according to Claim 33, wherein the processor determines a center of
17		mass of a component of the dynamic system; and
18		wherein the processor generates the rigid body input in accordance with a
19		feedback signal based on the center of mass of the component.
20		
21	55.	An apparatus which determines plural switch times for a voltage input into a
22		dynamic system having plural modes, the apparatus comprising:
23		a memory which stores computer-executable process steps; and
24		a processor which executes the process steps stored in the memory so as
25		(i) to generate a model of the dynamic system in terms of a modal analysis
26		each of the plural modes, (ii) to determine a response of the dynamic
27		system in terms of the modal analysis in the model, (iii) to determine an
28		expression for a contribution of each of the plural modes to a final location
29		of the system based on a corresponding response, the contribution of each
30		mode of the system being based on switch times for the voltage input, (iv)

1		to estimate values corresponding to the plural switch times, and (v) to
2		calculate approximations of the values corresponding to the plural switch
3		times based on the estimated values using the expression for the
4		contribution of each of the plural modes and the modal analysis in the
5		model of the dynamic system.
6		
7	56.	An apparatus according to Claim 55, wherein the processor re-calculates
8		approximations of the values based on a previous approximation of the values.
9		
10	57.	An apparatus according to Claim 56, wherein the processor re-calculates
11		approximations of the values a plurality of times, each time using a re-calculated
12		approximation of the values as the previous approximation of the values.
13		
14	58.	An apparatus according to Claim 55, wherein the processor generates a table
15		comprising plural switch times; and
16		wherein the processor estimates the values using the table.
17		
18	59.	An apparatus according to Claim 55, wherein the processor generates at least one
19		curve corresponding to the plural switch times; and
20		wherein the processor estimates the values using the at least one curve.
21		
22	60.	An apparatus according to Claim 55, wherein the dynamic system comprises a
23		data storage device; and
24		wherein the voltage inputs comprise voltage inputs to the data storage
25		device.
26		
27	61.	An apparatus according to Claim 55, further comprising the step of performing
28		input shaping on the voltage input after switch times therefor have been
29		calculated.
30		·

1	62.	An apparatus which reduces unwanted vibrations in a dynamic system, the
2		apparatus comprising:
3		a memory which stores computer-executable process steps; and
4		a processor which executes the process steps stored in the memory so as
5		(i) to determine whether greater than a predetermined level of vibrations
6		will be excited by an input to the system, and (ii) to modify the input to
7		the dynamic system in a case that greater than the predetermined level of
8		vibrations will be excited, where the processor modifies the input to the
9		dynamic system so as to reduce the level of vibrations in the system to less
10		than the predetermined level of vibrations.
11		
12	63.	An apparatus according to Claim 62, wherein the processor modifies the input to
13		the dynamic system using at least one of an input shaper, an inverse shaper, and a
14		filter.
15		
16	64.	A method of controlling a dynamic system in accordance with an input that is a
17		function of time so as to reduce unwanted vibrations in the system, the method
18		comprising the steps of:
19		generating a model of the dynamic system, the model defining system
20		position in terms of both time and a system input, and the model
21		constraining the system in accordance with one or more constraints
22		relating to the unwanted vibrations;
23		determining an input to the dynamic system which reduces the unwanted
24		vibrations based on the model generated in the generating step; and
25		controlling the dynamic system in accordance with the input determined in
26		the determining step.
27		
28	65.	A method according to Claim 64, wherein the model of the system comprises a
29		partial fraction expansion of third order equations that define the system.
30		

A method according to Claim 65, wherein the partial fraction expansion equations 1 66. 2 comprise:

$$Finalpos = \sum_{i=1}^{N} V_{i} A \Delta t$$

$$0 = \sum_{i=1}^{N} V_{i} \frac{Ab}{b-a} \left( e^{-a \left( T_{end} - T_{i} + \Delta t \right)} - e^{-a \left( T_{end} - T_{i} \right)} \right)$$

$$0 = \sum_{i=1}^{N} V_{i} \frac{Aa}{a-b} \left( e^{-b \left( T_{end} - T_{i} + \Delta t \right)} - e^{-b \left( T_{end} - T_{i} \right)} \right),$$

4 where Finalpos is the final position of a component of the dynamic system, T<sub>end</sub> 5 corresponds to a time at which Finalpos is reached, A, a and b are based on the system parameters, Vi are voltage inputs to the system, Ti are the times at which 6 7  $V_i$  are input, and ) t is a time interval at which  $V_i$  are input.

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A method according to Claim 64, wherein the input determined in the determining step comprises the fundamental limiting parameter of the system, the fundamental limiting parameter corresponding to a first parameter in the system to enter into saturation.

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68. A method of using a current command to control a system having voltage as a physical limiting parameter, where the system includes a current controller connected to a power supply, the method comprising the steps of:

17 inputting a current command to the system;

controller in saturation.

18 shaping the current command using a unity magnitude shaper so that the 19 current controller in the system goes into saturation; and 20 supplying voltage to the system from the power supply via the current 21

22

1	69.	A method of controlling a dynamic system having one or more feedforward
2		inputs, where one of the feedforward inputs corresponds to a fundamental limiting
3		parameter of the system, the method comprising the steps of:
4		altering a form of a feedforward input that corresponds to the fundamental
5		limiting parameter of the system so as to reduce unwanted dynamics of the
6		system.
7		
8	70.	A method according to Claim 69, further comprising the step of determining the
9		fundamental limiting parameter of the system by identifying a first parameter of
10		the system to enter into saturation.
11 ,		
12	71.	A method according to Claim 69, wherein the altering step comprises shaping the
13		feedforward input.
14		
15	72.	A method according to Claim 71, wherein the shaping is performed using Input
16		Shaping <sup>TM</sup> .
17		
18	73.	A method according to Claim 71, wherein the shaping is performed using one or
19		more filters.
20		
21	74.	A method according to Claim 71, further comprising the steps of:
22		identifying any nonlinear elements in the system;
23		wherein the shaping is performed after any nonlinear elements identified
24	ı	in the identifying step.
25		
26	75.	A method according to Claim 69, wherein the altering step comprises pre-
27		saturating the feedforward input and then shaping the feedforward input.
28		
29	76.	A method according to Claim 69, wherein the dynamic system comprises a data
30		storage device system; and

1		wherein the fundamental limiting parameter comprises voltage.
2		
3	77.	A data storage device system having one or more feedforward inputs, where one
4		of the feedforward inputs corresponds to a fundamental limiting parameter of the
5		system, the system comprising:
6		a memory which stores computer-executable process steps; and
7		a processor which executes the process steps stored in the memory so as to
8		alter a form of a feedforward input that corresponds to the fundamental
9		limiting parameter of the system so as to reduce unwanted dynamics of the
10		system.
11		
12	78.	A system according to Claim 77, wherein the processor executes process steps so
13		as to determine the fundamental limiting parameter of the system by identifying a
14		first parameter of the system to enter into saturation.
15		
16	79.	A system according to Claim 77, wherein the feedforward input is altered by
17		shaping the feedforward input.
18		·
19	80.	A system according to Claim 79, wherein the shaping is performed using Input
20		Shaping <sup>TM</sup> .
21		
22	81.	A system according to Claim 79, wherein the shaping is performed using one or
23		more filters.
24		
25	82.	A system according to Claim 79, wherein the processor executes process steps so
26		as to identify any nonlinear elements in the system;
27		wherein the shaping is performed after any nonlinear elements identified
28		by the processor.
29		

1	83.	A system according to Claim 77, wherein the processor alters the feedforward
2		input by pre-saturating the feedforward input and then shaping the feedforward
3		input.
4		
5	84.	A method of shaping an input to a dynamic system so as to reduce unwanted
6		dynamics in the system, the input to the dynamic system comprising digital data
7		sampled at a predetermined frequency, the method comprising the steps of:
8		identifying system vibrations that occur at the Nyquist frequency for the
9		system, the system vibrations corresponding to a sine wave having two
10		sample points per period; and
11		applying a three-pulse shaper to the input, wherein first and second pulses
12		of the three-pulse shaper are applied at the two sample points in a first
13		period of the input, and a third pulse of the three-pulse shaper is applied at
14		a first sample point in a second period of the input.
15		
16	85.	A method of generating an input to a computer-controlled dynamic system so as
17		to suppress vibrations therein, the dynamic system having a dedicated path solely
18		for a feedforward input from a controller to controlled hardware, the method
19		comprising the steps of:
20		determining a frequency of vibrations to be suppressed;
21		wherein, in a case that the frequency of the vibrations to be suppressed is
22		at or below a servo rate for the dynamic system, the method comprises the
23		steps of:
24		executing servo calculations for the system;
25		determining a servo output based on the servo calculations; and
26		outputting the servo output as the input to the dynamic system; and
27		wherein, in a case that the frequency is above the servo rate for the
28		dynamic system, the method comprises the steps of:
29		determining a trajectory value;
30		shaping the trajectory; and

1		outputting the shaped trajectory as the input to the dynamic
2		system.
3		
4	86.	A method of generating an input to a computer-controlled dynamic system so as
5		to suppress vibrations therein, the dynamic system having a path by which a
6		feedforward input and other signals are output from a controller to controlled
7		hardware, the method comprising the steps of:
8		executing servo calculations for the system;
9		determining a servo output based on the servo calculations;
10		storing the servo output in a memory;
11		determining a trajectory value for the feedforward input;
12		shaping the trajectory value; and
13		adding the servo output stored in the memory to the shaped trajectory
14		value so as to generate the feedforward input.
15		
16	87.	A method of controlling a dynamic system using an input command, comprising
17		the steps of:
18		shaping the input command to saturation;
19		inputting the saturated command until a first predetermined condition is
20		detected;
21		shaping a transition of the input command during deceleration from
22		saturation until a second predetermined condition occurs; and
23		following a preset trajectory until the dynamic system comes to within a
24		predetermined proximity of its final state.
25		
26	88.	A method according to Claim 87, wherein the preset trajectory comprises a curve
27		in a PV table.
28		
29	89.	A method of generating commands for a dynamic system in a first parameter
30		which maintain a limit in a second parameter, where the second parameter

comprises a fundamental limiting parameter of the dynamic system, the method 1 2 comprising the steps of: 3 determining a response of the second parameter in the dynamic system to a unit command in the first parameter; and 4 generating the command in the second parameter based on the response 5 6 determined in the determining step. 7 A method according to Claim 89, wherein the first parameter is current and the 8 90. 9 second parameter is voltage; and wherein the dynamic system comprises a disk drive. 10 11 A method according to Claim 89, wherein the response is determined by 12 91. iteratively solving a set of equations for the first parameter knowing at least the 13 14 second parameter. 15 92. A method according to Claim 91, wherein the set of equations comprises: 16

$$\sum_{i=1}^{N} A_i = 0,$$

1718

19

where A comprises amplitudes of the command in the first parameter at each time interval i, and N comprises a last time interval;

$$v_i = C_{vscale} \sum_{j=1}^{i-1} A_i,$$

2021

where v comprises a system velocity and C<sub>vscale</sub> is a constant;

$$P_{final} = \sum_{j=1}^{N} v_{i},$$

1 2

where P<sub>final</sub> comprises a final state of the system; and

3

$$-V_{
m lm} < \sum_{i=1}^{J} A_{j-i-l} \ R_i < V_{
m lim} \ , \ j=1 o N \ ,$$

4

5 where R comprises a pulse response of the system to the second parameter and

6 V<sub>lim</sub> comprises a limit in the second parameter.

7

8 93. A method according to Claim 92, wherein A comprises current, V comprises voltage, and R comprises a voltage response of the system.

10

11 94. A method according to Claim 92, wherein the values of R(i) are determined by

taking a peak value of the system response and sampling values of the system

response at subsequent time increments.

14

16

17

13

15 95. A method generating commands for a dynamic system in a first parameter (A)

which maintain a limit in a second parameter (V), where the second parameter (V)

comprises a fundamental limiting parameter of the dynamic system, the method

comprising the steps of:

determining a values for a command in the first parameter (A) at time

intervals (i) based on the following relationship:

$$A(i) = \frac{V_{\text{max}} - \sum_{j=2}^{i} A(i+1-j) R(j)}{R(1)},$$

1		where R comprises a pulse response of the system in the second parameter; and
2		formulating a command over time in the first parameter (A) based on the
3,		A(i) values determined in the determining step.
4		
5	96.	A method according to Claim 95, wherein A comprises current and V comprises
6		voltage.
7		
8	97.	A method of controlling a dynamic system having vibrations resulting from
9		movement, the method comprising the steps of:
10		identifying transitions of an input command to the dynamic system; and
11		shaping transitions of the input command so as to result in a system
12		response to the input command with reduced vibrations.
13		
14	98.	A method of controlling a system to reduce unwanted dynamics using commands
15		in both first and second parameters, where the second parameter comprises a
16		fundamental limiting parameter of the system, the method comprising:
17		commanding the system in the first parameter during a first mode of
18		system operation; and
19		commanding the system in the second parameter during a second mode of
20		system operation.
21		
22	99.	A method according to Claim 98, wherein the system comprises a disk drive;
23,		wherein the first mode of operation comprises tracking performed by the
24		disk drive; and
25		wherein the second mode of operation comprises seeking performed by
26		the disk drive.

1		
2	100.	A method according to Claim 92, 94, and 95, wherein $V_{\text{lim}}$ is varied in accordance
3		with i.
4		
5	101.	A method according to Claims 89 to 95, wherein constraints are added for
6		parameter slew rate limits; and
7		wherein the generating step generates the command in accordance with the
8		added constraints.
9		
10	102.	A method of rescaling a vibration-limiting input to a dynamic system, the method
11		comprising the step of:
12		linearly scaling amplitudes of the vibration-limiting input to produce a
13		scaled vibration-limiting input.
14		